



HVAC systems in a field laboratory for indoor climate study

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ABSTRACT

This paper presents the design of a HVAC system for a field lab. The design integrated mixing ventilation, displacement ventilation, low impulse vertical ventilation, personalized ventilation, natural ventilation, hybrid ventilation, active chilled beams, radiant ceiling and floor, and heat convectors. The field lab was designed for experimental research, education and demonstration of ventilation and air-conditioning principals with special focus on studying the impact of different air distribution and heating/cooling methods on human comfort and health. The system can also be used for testing under realistic conditions the performance of air processing units (e.g. a special air handling unit, an air cleaning devices, etc.) including their energy consumption and human response. The field lab can accommodate up to 50 occupants and supply 750 L/s of conditioned outdoor fresh air with the controlled room temperature in the range from 10 to 35 °C and relative humidity in the range from 15 to 80 %. The field lab can be used to test the performance of each system included in the field lab as well as the combined performance of two or more systems.

KEYWORDS

Indoor environment, ventilation, field experiments, indoor air quality and thermal comfort.

INTRODUCTION

Indoor environment comprises both thermal environment and air quality. In many indoor climate studies, certain environments are to be established for subjective and/or objective evaluations. Many studies of this type are conducted in climate chambers and others in buildings of real space. The climate chambers usually provide well controlled indoor climate and the impact of separate parameters can be studied. However, the climate chamber environment is not realistic and the chamber is usually designed for a specific objective. Field studies in real spaces have a realistic but difficult to control environment. Both climate chambers and real building spaces usually lack flexibility in studying the performance of different climatic systems, especially the combined effect of different climatic systems on indoor environment and on human comfort and work performance. Many studies, especially, the studies investigating the effect of indoor environment on human productivity require controlled realistic environment for the exposure of human subjects. Such studies are difficult to be conducted in climate chambers and real spaces in buildings. For such studies, field labs are the best choice. A field lab makes it possible to perform studies in environment similar to that in real life which can be controlled almost as good as it is in climate chambers.

The field lab presented in this paper is a 72 m² room that is used as a classroom as its primary function. The room can also be arranged as an open plan office or split in several office rooms. The field lab is equipped with a climatic system that includes several subsystems with different scenarios for heating, cooling and ventilation. The subsystems can operate either individually or collectively to achieve a required effect of heating, cooling, ventilation and energy utilization. Except for research, the field lab can also be used for teaching and demonstration of different heat, cooling and ventilation approaches.

DESIGN CRITERIA AND CONSIDERATIONS

Outdoor air rate

The field lab has a volume of $12 \times 6 \times 3 \text{ m}^3$. It is a classroom that can accommodate up to 50 occupants. The room has one facade with 42% area of glass windows facing to the east. One of the design criteria for the field lab is that the ventilation system should be able to supply sufficient outdoor air rate for 50 occupants. Considering ventilation requirement prescribed by the existing standards (CEN, 2007), the ventilation system is considered to supply more than 500 L/s of outdoor air rate to insure 10 L/s per person of outdoor air supply for each occupant when the room is fully occupied (Category I environment). Considering that previous studies indicated that outdoor air rates below 25 l/s per person in offices increase the risk of SBS symptoms, increase short-term sick leave, and decrease productivity (Wargocki et al., 2002), a total outdoor air ventilation rate of 750 L/s was designed for the field lab. With this ventilation rate, 25 L/s per person of outdoor air rate can be supplied at a reduced occupancy of 60% (30 occupants), which is a normal occupancy rate of this classroom.

Indoor air temperature and humidity

Temperature and moisture content of the air in the field lab is designed in the range from 10 to 35 °C and 4g/kg to 20g/kg respectively. In this range of temperature, thermal sensation can be in the range from -3 (very cold) to +3 (very hot).

Ventilation and indoor climate control scenarios

The indoor climate in the field lab can be controlled by seven different ventilation methods: mixing ventilation, displacement ventilation, low-impulse vertical ventilation, personalized ventilation, natural ventilation, hybrid ventilation and ventilation from active chilled beams. Except for using these ventilation methods, the thermal environment of the field lab can also be controlled by thermal radiation using radiant ceiling panels and floor as well as by convectors.

The field lab is located on the third floor of an office building. To guarantee the quality of supplied outdoor air, the outdoor air is taken from the garden of the building and exhausted from the roof of the building.

HVAC SYSTEM OF THE FIELD LAB

The main ventilation system includes three air handling units – pre-heating unit, main air conditioning unit and PV air conditioning unit (see Figure 1).

Pre-heating unit

The pre-heating unit is located in the basement of the building close to the air intake from the garden. The pre-heating unit includes an air filter, a shut off air damper, a heating coil and a fan. The main purpose of pre-heat unit is to pre warm the outdoor air in winter season to prevent freezing in the duct from basement to the third floor. The fan in the pre-heating unit provides enough pressure to overcome the resistance of the air channel from basement to the third floor of the building and to insure over pressure in the outdoor air supply channel to prevent the polluted indoor air from getting into the system due to the possible leakage.

Main air conditioning unit

The main air conditioning unit includes two sections - the outdoor air conditioning section and main supply air conditioning section. The outdoor air conditioning section is designed to control the hygro-thermal condition of the outdoor air supplied to the main supply air conditioning section. The main purpose of this section is to provide fresh outdoor air and to simulate different outdoor climate conditions, e.g. simulate winter outdoor climate conditions when running experiment in summer or vice versa. This unit has a full function of air

conditioning, e.g. heating, cooling, humidification (by extension) and dehumidification. It includes a EU7 air filter, a cooling coil, a heating coil, and an air damper. The cooling coil was designed in front of the heating coil so that the system can simulate the outdoor climates: warm and dry, cold and dry, warm and humid and cold and humid.

The main supply air conditioning section is used to control the climate in the field lab. This section is designed after the mixing of outdoor air and recirculation air. It has also a full function of air conditioning. The main supply air conditioning section includes a EU7 filter, a cooling coil, a heating coil, a fan, a sound attenuator and a steam humidifier. This section can provide up to 750 L/s of total supply airflow. Among this airflow, the proportion of outdoor airflow can be adjusted from 0 to 100%. The fan in the main supply air conditioning section is equipped with a frequency controller so that the system can run in either CAV or VAV mode.

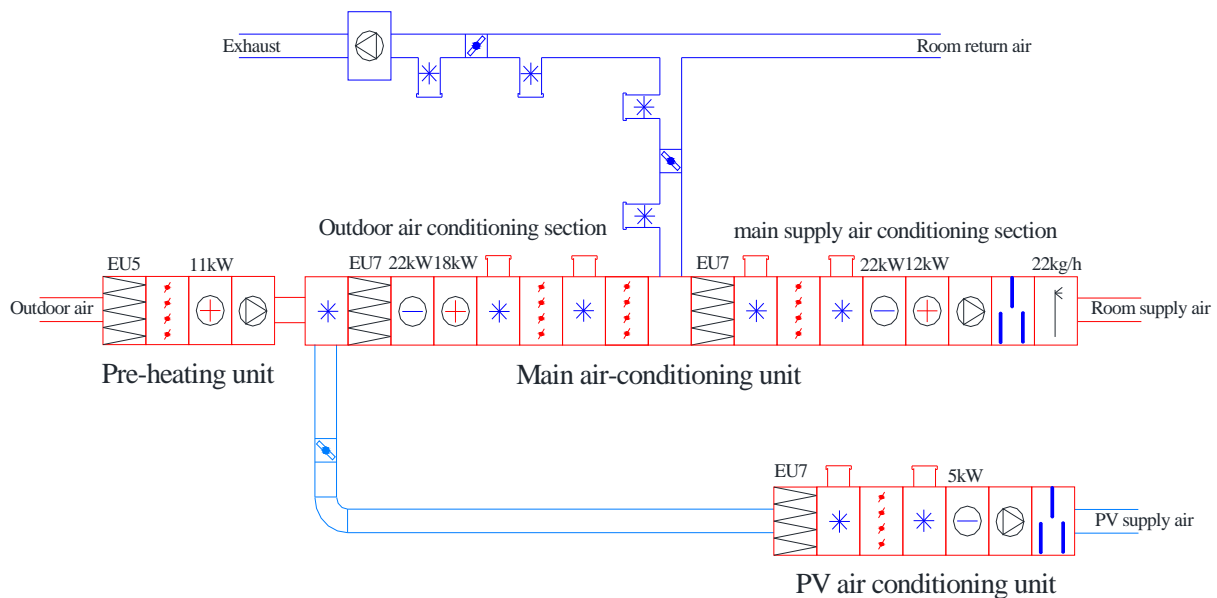


Figure 1. Schematic diagram of the ventilation system used in the field lab.

PV air conditioning unit

The PV air conditioning unit provides airflow to the personalized ventilation (PV) air terminals. This system has a filter, a cooling coil, a fan and a sound attenuator. The system can only cool the air before the air is delivered to the PV terminals. If heating is required, it will be done locally at the PV terminals. The PV air conditioning system can provide up to 300 L/s of airflow for 30 workstations with PV air terminals. The fan is equipped with a frequency controller. The speed of the fan can be controlled to maintain the pressure in the main duct of the PV air supply system at a constant level. With this control, the airflow at each PV terminal can be controlled independently without coupling to each other.

System extension

In each of the air handling units, it is designed a possibility to extend the function of the system by subjoining an additional device. This is done by adding two extension openings (indicated by “*” in Figure 1) in the air handling unit with a damper built in between. The two extension openings are usually closed by caps and the damper is opened. In case that an additional device is to be added into the system, the damper between the two extension openings will be closed and the air will be redirected from the opening before the damper into an additional device and back to the air handling unit from the opening after the damper. The

design is particularly useful in the case when the air to be processed in the air handling unit needs a special treatment and the function is not included in the air handling unit (e.g. a special cleaning process). In this case, the additional air handling equipment can be connected easily into the field lab ventilation system. The design can also be used to test the performance of special air processing equipment.

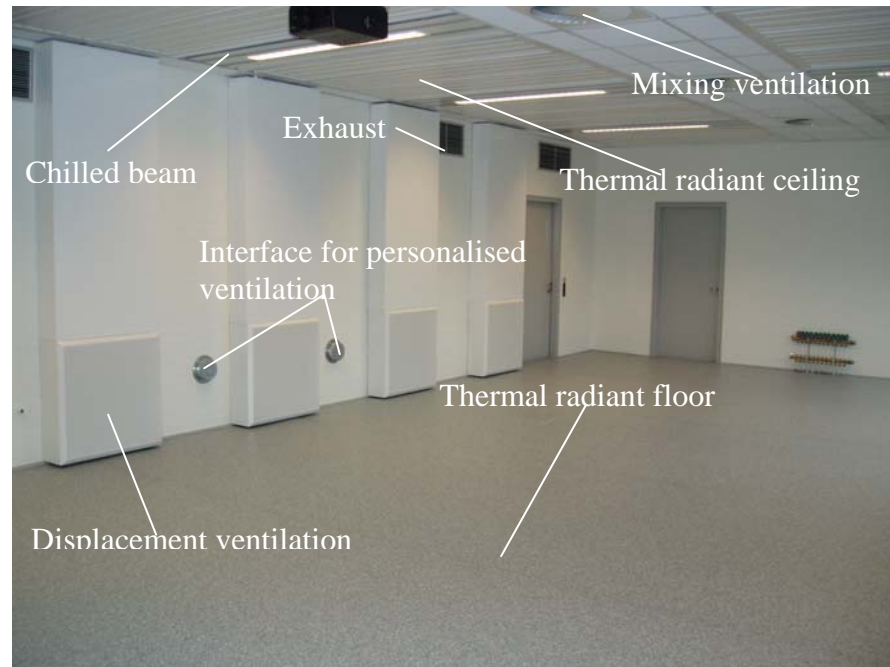


Figure 2. The internal view of the field lab.



(a) Air system



(b) water system

Figure 3. The ventilation system of the field lab.

Radiant heating and cooling system

Both ceiling and floor can be used for radiant heating and cooling by changing the supply water temperature to the ceiling or to the floor. In the heating mode, the supply water temperature is controlled by the mixing rate of the hot water supply and the recirculation water flow. In the cooling mode, the temperature control of the ceiling and floor is in the same way as used in the heating mode except that the supply water will be switched to the chilled water. In this way, the surface temperature of the ceiling can be controlled in the range

from 10 to 50 °C and the surface temperature of the floor can be controlled in the range from 15 to 35 °C. The radiant ceiling and floor are divided into 10 sections. Each can be controlled on and off individually.

Natural and hybrid ventilation system

Four special motor windows were installed in the field lab. The windows were automatically controlled either according to the outdoor climate or a prescheduled opening plan. A weather station is installed on the roof of the field lab to provide outdoor climate information (e.g. temperature, humidity, wind speed and direction) for the control of the window opening. Control of the exhaust fan of the main ventilation system can be separated from the main system and be controlled together with the motor windows to assist the natural ventilation and makes a hybrid ventilation system.

Terminal devices of the HVAC system

Figure 2 and 3 show the field lab and its HVAC system. Four diffusers for the mixing ventilation were installed in the middle of the ceiling. The diffusers can be easily changed to ensure different air distribution patterns (swirl jet, wall jets along the ceiling, etc.). Five diffusers for the displacement ventilation were installed on one side of the room. The mixing diffusers placed in the middle of the ceiling can be removed and a textile terminal for low impulse vertical ventilation can be attached instead. Eight active chilled beams are installed in two columns along the room. They are combined with devices to provide the main lighting of the field lab. The PV diffusers have to be installed together with tables and are not shown in the figure.

Control system of the field lab

The whole HVAC system in the field lab is controlled by a DDC computer. The DDC computer can control each component individually and the control function can be programmed to achieve a fully automatic and flexible control according to the requirement of experiment. Sensors (e.g. sensors measuring water flow rate, inlet and outlet temperature of each heating and cooling coil, ceiling panel and floor) were also installed to measure the energy consumption of each component in the HVAC system for analyzing the energy consumption of different climatic control scenarios.

DISCUSSION AND CONCLUSIONS

The use of the field lab for the indoor environmental studies has been tested. It provides a well controlled environment for both objective measurements and subjective assessments. The field lab can be used for research with different objectives. The following advantages may be the most significant.

1. The field lab provides a realistic indoor environment and setup for experiments. For example, this field lab is a classroom. It can be used to study the comfort and learning performance of the audients in the classroom. The audients will feel very natural to work in this room. This will avoid psychological impact on their subjective assessment of environment or on their working performance due to the unrealistic environmental exposure;
2. This field lab can be used to compare different ventilation and heating/cooling scenarios, their control strategies and energy consumptions. The field lab was designed to switch climatic system from one to another easily. This function is particularly useful for training

the HVAC students and for demonstration on the advantages and disadvantages of different HVAC designs;

3. A special advantage of this field lab is that it can be used to study the performance of a combined climatic system. For example, a room with displacement ventilation may require addition heating in winter since the supply air temperature from the displacement ventilation is always few degrees lower than room air temperature. Thus the performance of displacement ventilation combined with radiant heating from ceiling or from floor or displacement ventilation combined with heat convectors can be studied. In summer, the displacement ventilation may not be able to supply enough cooling due to the limitation on the supply air temperature and airflow rate to avoid draft. In this case, displacement ventilation may be combined with chilled ceiling or chilled floor. Other indoor climate control strategies, such as hybrid ventilation (natural ventilation combined with mechanical ventilation), personalized ventilation combined with warm or chilled ceiling or floor, or personalized ventilation combined with mixing, displacement and natural ventilation can also be tested in the field lab. These and other combinations of the systems can be achieved easily by the HVAC system of this field lab;
4. The field lab can provide a wide range of indoor climate control with better control performance compared to a normal air-conditioned and ventilated space. This makes it more convenience for the field lab to be used for conducting the experiment that requires a very stable indoor environment independent to the outdoor climate. The control of the systems also allows for establishment of wide range of non-uniform environments to be studied.
5. A unique design of this field lab is that the ventilation system can be extended according to the purpose of the experiment. It allows subjoin an additional air handling unit into each part of the ventilation system (e.g. outdoor air section, exhaust section, recirculation air section, room supply air section after the mixing of outdoor air and recirculation air, or PV section). Thus the field lab can also be used for evaluating the performance of special air process equipment (e.g. an air cleaning device) in a real environment.

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